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A.N.H.S.
17 Sept. '26 Gift Miss Nutting

The Teaching of the History of Science

(Second article) (1)

What is the present status of the teaching of the history of science in European and American universities ? The lists and announcements of courses which have been published in various journals (2), may give the reader a very misleading impression. For these lists are many and some are quite long, but most of it is mere bluff. For example, many such courses have been extemporized in America, but, with one exception (CAJORI), I do not know of any course delivered by a lecturer having the rank and emoluments of a professor and devoting himself exclusively to it. To be sure, some of these courses offered as a « side show » by scholars whose main business is to study and to teach something totally different, may be very interesting. Among others, the lectures which the physiologist L.-J. HENDERSON has been giving at Harvard since 1911 have been eminently successful. This exception does not prove anything. Nor does BERTHELOT's example prove that it is generally possible to pursue simultaneously experimental and historical investigations with any considerable success. We owe some of the best work in every field to the capricious efforts of *dilettanti*, but we can never depend upon them and we must of necessity expect the main advances in knowledge to be made by men whose sole duty is to make them and who give their every thought to it. The case of HERMANN GRASSMANN is particularly strange. About 1852, being then in the forty-third year of his age and probably discouraged by the cold reception of his *Ausdehnungslehre* (first published in 1844, it

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(1) The first essay, bearing the same title, appeared in the *Scientific Monthly*, September 1918, vol. VII, p. 193-211. The present paper does not supersede the first one, but completes it.

(2) By ENESTRÖM in the late *Bibliotheca Mathematica;* by SUDHOFF and GÜNTHER in the *Mitteilungen*, by MIELI in his *Archivio*, by F. E. BRASCH in *Science* and by myself, though rarely, in *Isis*.

remained practically unknown for twenty years !), he turned his attention to Oriental studies, and he conquered fame as a Sanscrit scholar before being recognized as one of the greatest mathematicians of his day. It does not follow from this that it would be wise to intrust Vedic exegesis to mathematicians, or *vice versa* to expect the Sanscrit instructor to offer, as an additional attraction, some lectures on higher algebra or vectorial analysis. To expect a professor of history or science who is not specialized in the history of science to give a course on this subject is equally foolish. Yet this sort of foolishness or wickedness is becoming very common, for every university seems now anxious to add some course on the history of science to its program, though none is willing to pay the price of it.

This is in itself sufficient to prove that the signification and peculiarities of such courses are not yet understood, even by those who organize them. To form some idea of the present status of this teaching it will be better not to consider the number of courses offered, nor to enumerate the lecturers, for we should risk being deluded. We will consider only such courses as are offered year after year by specialists and which are placed on the same academic footing as other fundamental studies. Let us ask, first of all, how many chairs are devoted to the history of science? The brevity of the answer will be a sharp contrast with the length of the make-believe lists to which I previously alluded.

In America, I do not know of any chair devoted to the history of science proper, but FLORIAN CAJORI is professor of the history of mathematics at the University of California. Of other positions enabling the incumbent to cultivate these studies with relative freedom from material care, I know only the one which was founded for me in 1918, by the Carnegie Institution of Washington. If I am not mistaken, that is all for the New World!

Matters are hardly better in the Old World, at least so far as the history of science proper is concerned. I know of only one chair dedicated to it, the one at the Collège de France, which is now occupied by PIERRE BOUTROUX (1). Mr. BOUTROUX wrote me a few months

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(1) His title is « professeur d'histoire générale des sciences ». (While correcting the proofs, I hear that ABEL REY is now « professeur d'histoire de la philosophie dans ses rapports avec les sciences » at the Sorbonne, but that is another subject, as I have shown in my first paper.)

ago that for some time to come his lectures will deal with the history of the principles of mechanics. His chair is the very one which poor COMTE had vainly tried to have established, but which was not founded until 1892, thirty-five years after COMTE's death, and intrusted to PIERRE LAFFITTE. In 1903, the latter was succeeded by G. WYROUBOFF instead of PAUL TANNERY, who was obviously the right man. If TANNERY and later DUHEM had been appointed to it (it appears that political prejudice was the only obstacle to their nomination), this chair would have behind itself the noblest tradition imaginable; but it was not to be. Let us hope that PIERRE BOUTROUX is now inaugurating a new tradition which may make us forget the brilliant opportunities which were lost in the past.

The chair of the Collège de France is to-day the only one in the world devoted to the history of science. It is true, EDMOND GOBLOT of the University of Lyons bears the title of « professeur d'histoire de la philosophie et des sciences », but the emphasis is laid on philosophy, not on science, and GOBLOT's own work is chiefly in the field of logic (1). I should mention as being in the same line the course offered at University College, London. ABRAHAM WOLF is in charge of it with the title of professor of logic and scientific method. His own work is also exclusively in the field of logic (2). Short courses on the history of science have lately been organized under his direction (3), but as I am dealing here only with regular and permanent courses and not with makeshifts, I can not consider them.

The situation is even worse than it seems at first sight, if one remembers how many chairs are devoted to historical studies. In the latest Harvard catalogue (1920-1921), I find that not less than thirty-five members of the faculty are primarily engaged in historical teaching of some sort, the history of science alone being excluded. There are thus in the world thousands of professors of history, but only one of them is teaching the history of science! Shall we weep or laugh? The history is taught of everything under the sun, except science; yet we call this age of ours, the age of science! A moment's reflection will convince anyone that the only human activity which is truly

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(1) *Isis*, III, 306.

(2) I know two books of his : *The existential import of categorical predication*, Cambridge 1905, and *Exercises in logic and scientific method*, London, 1919.

(3) *Isis*, III, 419.

cumulative and progressive is scientific activity, — the acquisition, accumulation and transmission of knowledge. The only conquests which are final are our conquests over ignorance. Thus any history of humanity should be focussed upon the progress of knowledge; that should be the thread, the *leitmotiv* of the human epos. Yet that very part of our annals is either ignored or treated in such offhand and scandalous fashion that complete silence would be more reverential.

I have spoken thus far of the history of science in general. The situation is better with regard to special sciences or groups of sciences. CAJORI's teaching at Berkeley has already been mentioned. The chair of Heidelberg has been made famous for ever by the late MORITZ CANTOR (1). There may be, at least in Germany, a few other chairs devoted to the history of mathematics. It is in the medical domain, however, that historical studies have been organized in the most elaborate manner. The Institute for the History of Medicine founded at the University of Leipzig by the munificence of TH. PUSCHMANN has become, under the direction of KARL SUDHOFF, one of the greatest historical institutes in the world. There are also historico-medical institutes and chairs at the University of Vienna (MAX NEUBURGER) and Jena (TH. MEYER-STEINEG) and there may be still others : I have quoted those which are, and justly so, the best known. I do not know of any chair for the history of medicine in any other country, though lectureships are fairly common. At one time (1863-1891), ANGELO CAMILLO DE MEIS (2) was professor of the history of medicine in Bologna, but he was never replaced.

The privileged status of the history of medicine calls for some explanation. How shall we account for it? For one thing, the history of medicine has always attracted far more attention than the history of other sciences or techniques, because of its intensely humane character. Try as you will, the history of the medical art can never be divested of its human element. The average man is more likely to be interested in the riddles of disease and death, which confront him at every step, than in the principles of geometry or mechanics. This interest will easily take an historical turn, for the solution of riddles evokes anecdotes; men are naturally fond of anecdotes, and anecdotes belong to the past. On the other hand, the clinical and historical points of view have something in common and

(1) He has been succeeded by KARL BOPP.
(2) *Isis*, IV, 421.

the physician is perhaps more tempted than any other scientist to delight his well-deserved leisure with historical research. This explains why the literature of medical history is so enormous and also why so much of it is rather of an inferior quality, — more in the nature of anecdote, gossip and idle antiquarianism than of philosophical history.

The most important feature of the history of medicine, however, is that it is, in fact, far more comprehensive than its name would suggest. Textbooks on the history of medicine are not by any means restricted to medical topics; they deal as well with anatomy, physiology, botany, even to a certain extent with chemistry, arithmetic, astrology, etc. For the mediaeval period down to the xvith century, some of these histories might be passed off as histories of science. At any rate, physicians are generally ready to take them as such, for they are not philosophically minded, they hate abstractions, they ignore the more exact sciences and are satisfied that the history of medicine gives them all that is really worth knowing of the history of science.

Thus did it come to pass that the history of medicine, — having considerably enlarged its natural scope and received a sufficient elaboration at a comparatively early date, — filled the needs and gratified the curiosity of a large part of the students who might have become interested in the history of science proper. From this point of view it may be said that the earlier and greater success of historico-medical studies has temporarily impeded the progress of our own. At all events, this does not matter much, for whatever historical research was done by historians of medicine either in their own or in neighbouring fields, *is* done. They have helped to develop methods which can easily be extended to similar investigations with regard to other sciences, they have created model institutions which it will not be difficult to render more comprehensive, they have awakened an historical interest which may be progressively diverged to the broader sphere. And whatever errors of interpretation were due to their peculiar point of view, their onesidedness and their ignorance, will be easily righted in the course of time.

To appreciate properly the present situation of the teaching of the history of science, it will be well to compare it with that obtaining in other historical departments comparable to it, chiefly the history of art and the history of religion. A comparison with the latter is particularly apposite, and I will come back to it presently. As to

the former, its situation is incomparably more favorable. There is no college, I am sure, that has not at least one chair devoted to the history of art. In the larger colleges a whole department is devoted to art, though the greatest part of its activity is naturally absorbed by practical rather than historical subjects. But this teaching suggests another comparison. We have seen that the history of medicine has to a large extent supplanted the history of science proper. In the same way, the history of the so-called « fine arts » has superseded the history of art to such a degree that the average man very often mistakes the former for the latter. This comparison should not be carried too far, however, because the situations of both cases are reversed. The history of the more abstract and the purer kind of art has drawn most of the attention, while the applied or decorative arts have been comparatively neglected. On the other hand, it is the applications, chiefly the medical applications, of science that have first engrossed the historian's interest, at the expense of the more abstract disciplines. To put it more briefly, man's historical curiosity has been (and is still) arrested primarily by the highest forms of art and the lowest forms of science.

II

A comparison with the history of religion is extremely instructive, for the present status of our studies is very similar to its own some fifty years ago. Before that time the history of religion had been considered by the theologians and the educated public either with undisguised disfavour, or (and this became gradually the more common attitude) with that polite indulgence which one readily grants to curious but futile investigations. When the first courses were organized, it was thought that almost any theologian could prepare them, an assumption which was the further from the truth in that at that time scientific textbooks on the subject were not yet available. The first good textbooks appeared only at about the end of the last century (1). The first chair devoted to the history of

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(1) Cornelis P. Tiele, *Geschiedenis van den godsdienst tot aan de heerschappij der wereldgodsdiensten*, Amsterdam, 1876 (English translation, London 1877). — Chantepie de la Saussaye, *Lehrbuch der Religionsgeschichte*, 2 vol., Freiberg, 1887-1889. The second edition prepared by Chantepie with

religion was established in Lausanne in 1871. Then followed in quick succession : Genève and Boston, 1873; Oxford (Manchester College), 1876; Groningen, Leyden and Utrecht, 1877; Amsterdam and Upsala, 1878; Paris (Collège de France), 1880; Brussels, 1884 (1). In 1870, there was not a single chair of the history of religion, and the scientific and systematic study of this subject had not yet begun. Thirty-four years later, in 1904 (2), there were scattered all over the world not less than thirty chairs, and the history of religion had become solidly established as an independent discipline, having its own methods and instruments, its own traditions. The days of chaos were past; it was no longer believed that anyone could study — not to say, teach — the history of religions without special training; museums and schools had been founded, and their doors were carefully guarded.

The reader will readily forgive me for having spoken of the history of religion at a greater length than he would probably expect in an essay on the history of science, for could anything give us more courage and inspiration than this brief history of a discipline so closely related to our own?

In 1870, the history of religion did not exist; to-day, it is safe to say that at least one chair is devoted to it in every university or seminary worthy of the name.

This preamble makes it easy to explain my own ambition. We are starting almost from the point whence the TIELES and the CHANTEPIES started fifty years ago. We must emulate them and exert ourselves to such an extent that fifty years hence the faculty of no university or college will be deemed complete if one at least of its members be not exclusively engaged in the study of the history of science.

I am writing this in the autumn of 1921. I am ready to fight for

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the assistance of a few other scholars (1897, French translation 1904, third German edition 1905), was probably the first satisfactory textbook, though it did not include Christianity.

(1) It is interesting to note that small nations like Holland and Switzerland took the lead. Holland's credit is particularly great because the teaching of the history of religion was from the beginning in the hands of masters : TIELE in Leyden and CHANTEPIE in Amsterdam. The first incumbents in Paris and Brussels were respectively ALBERT RÉVILLE and GOBLET D'ALVIELLA.

(2) My information is derived chiefly from LOUIS HENRY JORDAN, *Comparative religion. Its genesis and growth*, Edinburgh, 1905.

this cause and I will not retire alive from the arena until I have won (1). I will not lay down my arms if at least twenty chairs devoted to our studies do not exist by the year 1941, — and if there be not at least fifty of them by the year 1971, I will not hesitate to jump out of my grave and fight all over again.

The history of religion has been established as an independent discipline during the last quarter of the past century; it is our sacred mission to establish the history of science as an independent discipline during the second quarter of this century. We must work so hard and so well that other scholars will be obliged to recognize the independence and the fundamental importance of our studies; we must elaborate and systematize the necessary methods and instruments; we must create traditions which enforce obedience, discourage amateurish efforts and render unskilled teaching unthinkable.

It is also our particular duty of the moment to make it clear to university presidents, deans and other authorities that, if the teaching of American or Greek history is considered as a man's job, *a fortiori* the teaching of the history of science must be. For in the first case there are excellent textbooks, dictionaries, and various other intellectual tools; the subject has been studied from every angle; the main points have been emphasized and the moot questions discussed over and over again; the teaching itself is well-nigh standardized. In the second case, there are only numerous and often conflicting monographs written by various scholars in many languages; there are no exhaustive textbooks (2) and the instructor is left to find and clear his own way in the bush. It is our duty to hammer into their heads the conviction that to intrust the teaching of a new subject to non-specialized scholars and especially to those who have already other scientific obligations and can devote only a small part of their time to the new ones — is a joke and a very bad one at that. And when they do so it is our duty to proclaim their foolishness, their incapacity, and to give them generously all the discredit and ridicule which bad educators and ignorant administrators fully deserve.

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(1) To avoid any misunderstanding, I hasten to add that I have personally no wish to become a professor. *Sic ego non mihi...*

(2) FR. DANNEMANN'S book is satisfactory as far as it goes, but it is elementary (*Isis*, IV, 110).

III

It is useless to discuss the teaching of the history of science if one has not thoroughly understood the double origin, the double nature of this discipline. Its name is sufficiently significant, but one often overlooks the obvious. The *history* of *science* is a historical discipline; it is also a scientific discipline. The historian of science must have a sound knowledge of two sets of facts : historical facts and scientific facts. He must be familiar with the methods required to ascertain and to interpret these two kinds of facts. It would serve him little to be a good scientist, if he had no historical sense, no historical training; it would serve him less to be a well-trained historian if he had no understanding, no knowledge of science.

To make this clearer, let us consider again the branches of learning more comparable to our own : the history of art and the history of religion. If the historian of religion were deprived of religious feeling and religious experience, he would be doomed to make capital blunders at every step. His learning would be but dead and senseless pedantism; it would be worthless. The case of the historian of art is even more manifest : of what use would it be to him to know the names and dates of the old masters if his heart did not understand their silent voices ? The art critic who has not himself the temperament of an artist is doomed to failure. He may know all the details; he is unfit to understand the essential.

In the same way, the historian of science who does not grasp the scientific facts and theories (it does not generally suffice to know the definite facts in question; one must be able to grasp whole series of related facts and to seize the trains of thought involved by them), who has no scientific experience and feeling, is bound to make essential mistakes, irrespectively of his learning. Historical and scientific errors must be equally avoided, but many historical errors are only venial offences, while the scientific errors are deadly sins. The former, indeed, imply merely a misapprehension of the accessory circumstances, while the latter prove that the very substance of one's investigations has not been understood. Imagine a teacher explaining to his audience the theory of homocentric spheres. He might fail to introduce it properly, and the lack of historical perspective would unduly increase Eudoxus' fame at the expense of

his predecessors; this would shock us but we might forgive him. Imagine now that his historical account be perfect but that he proves his inability to understand the theory itself. What confidence could we have in him ? When the fundamental facts are wrong (and in our case, these are the scientific facts) we do not even care to know whether the historical circumstances are right or not.

One may object that those who deal with mediaeval or oriental science do not need as much scientific knowledge. That is true but only to a certain extent. It is true enough, for instance, that we owe some of the best work on mediaeval science to historians who had not received any scientific training. Such exceptions do not prove anything, and we must remember on the other hand that the two greatest students of mediaeval science of our time are (or were) professional scientists : KARL SUDHOFF and the late PIERRE DUHEM. It is obvious that their work could not have been done by laymen. Besides, the field of mediaeval science gives us but too many examples of erudite research vitiated by scientific ignorance. A common source of error is the confusion between mediaeval and modern terminology, and the extension to the former of connotations of a much later date. This applies particularly to studies on Hindu science. Finally, I must point out that there is a great difference between learning and teaching. A mediaeval scholar without scientific training may yet carry on investigations of great value, for if he be prudent enough to avail himself of expert advice he will easily avoid the scientific pitfalls. He may thus produce excellent papers and yet remain unqualified to teach mediaeval science, for he could not appeal to his scientific adviser in the course of a lecture, and a teacher must be able to give additional elucidations and to answer troublesome questions.

I hope that my emphasis upon scientific errors will not be misconstrued. If I were to say that killing a man is a worse offense than cheating at cards, this would not mean that I condone cheating. There is a hierarchy of sins, there is a hierarchy of errors. When I say that, for the historian of science, scientific errors are generally mortal, I do not mean that historical errors are of no importance. We must try to avoid them by all means. Historical facts are valuable only to the extent that they are accurate; it would be foolish to collect worthless material. Our ideal of historical truth can never be placed too high.

IV

Granted the priority and essentiality of scientific facts, it follows that the historian of science, especially the one engaged in teaching, should be primarily a scientist and secondarily a historian, a philosopher. There is another reason, hardly less cogent, why his training should be primarily scientific. This is the well-known fact that scientific knowledge, and even more so, scientific methods and points of view, must be assimilated while one is young; that is the more true that the sciences considered are more abstract. In the extreme case of mathematics, it may well be said that he who has not studied them before he was twenty or twenty-five will never be able to master them, for he will never again find the time nor have the persistent and docile energy which are needed to complete such systematic training. The same might be said of experimental work; experimental habits must be made in youth; we can not fully understand the experimental spirit unless early practice has caused it to impregnate our own substance (1).

On the other hand, historical training, difficult as it is, can be eventually undertaken later. The true historical spirit is innate rather than acquired. And as to historical understanding, it can but increase as we gain more knowledge of the world, more experience of life. Children cannot possibly understand history; they misunderstand it systematically. Indeed, there are many historical facts which can not be appreciated except in the maturity of one's age, when personal experience has revealed the true meaning of human passions, when one has been able to measure their violence with one's own heart. It takes many storms to make a good sailor. For example, familiarity with the political conditions of one's own day will help one to judge the political problems, the political passions and crimes of the past. Thus the older one becomes, the better does one understand political history, — and history in general.

One must also take into account the extreme interdependence of scientific facts, the rigorous concatenation of scientific theories,

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(1) It is for these reasons that I advise young students interested in the history of science to study as much mathematics and carry on as much laboratory work as they can. It is for them a matter of now or never.

which makes it generally far more difficult to understand isolated facts or theories than is the case in the historical domain. One unfamiliar with physics and chemistry will be unable to read with any profit a book on spectroscopy, while he will find no essential difficulty in reading and following the history of Ethiopia even if his previous knowledge of the subject, and of history in general, is very small.

I think we may now consider as proven that early and thorough scientific training is the prime qualification of the historian of science. The next question is then naturally, what should be the extent of this training ? To be ideal it should be encyclopaedic. Such training is not at all irrealizable, but the number of people having undergone it is of necessity very small (not because of any insuperable difficulty, but simply because of a lack of organization, because it is not « done »; I will come back to this presently) and we must take into account existing conditions. We must frankly admit that if the teaching of the history of science were suddenly organized on a large scale — if, say, ten chairs were established at once — it would be well-nigh impossible to find men fully qualified to occupy them. That would be no serious obstacle, however, for it would be much easier to find scholars ready to teach the history of one science or group of sciences, and the more general teaching might be temporarily replaced by a more special one. It is in the nature of things that the first teachers, the pioneers, are inferior to the later ones, even though their inspiration be of a higher quality. Our best works are nothing but stepping stones for our followers.

It would be unwise to insist at once upon the necessity of an encyclopaedic training, but there are minimal requirements which should be satisfied in any case. It would be unadvisable, for instance, to intrust such teaching to men having no experimental training whatever. This training can not be obtained simply by the making of artificial experiments -- such as those prepared for the students in college laboratories — the results of which are known beforehand. It is necessary to have made at least a few genuine experiments, experiments in the unknown. A minimal knowledge of mathematics should also be required (except for those restricting themselves to the history of medicine), and this minimum should include at least some familiarity with analytic and synthetic geometry and infinitesimal calculus. For without such knowledge it would

be impossible to speak tolerably (1) of such men as ARCHIMEDES, APOLLONIUS, DESCARTES, HUYGENS, NEWTON, LEIBNIZ and EULER, and a course on the history of science containing no account of them would be very much like the play of HAMLET without HAMLET.

Keeping these minimal requirements in mind, one could rightly expect the teacher to be able to expound the whole history of science down to the beginning of the last century (with more emphasis on the subjects he knows best and a more superficial account of the others). He should not be expected to explain the latest developments except of those sciences with which his special training has caused him to become more familiar.

Courses on the history of science should have the same flexibility as courses on the history of art or religion. The teacher to whom the latter are intrusted should not necessarily be expected to devote as much attention to every religion or sect or to every phase of their development. If he were an Arabic scholar, he would be justified in giving relatively more time to Islam and thus letting the students share the fruits of his studies, or else a bent to ethnography might induce him to treat more fully the more primitive stages. A professor of art might be more interested in painting and (after due warnings to his audience) there would be little harm in his neglecting relatively the other arts to lay more emphasis on the history of painting. In this case, however, he would be frequently obliged to deal with the other branches of art merely to explain the development of his favourite one. In the same way, the historian of science could never neglect too much any branch of knowledge, for the evolution of every branch is simultaneous and none is independent of the others. It is impossible to understand the development of any one science without reference to the others. Even then, the professor of the history of science should remain unusually free in the selection and the treatment of his subject. Administrators should always be ready to sacrifice programs to personalities. They should never forget that the presence of a real scholar in their midst is an inestimable blessing. Even if he be a poor teacher, his very presence

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(1) I do not say *to explain* their work, for this would require a far deeper knowledge of mathematics. For example, a very sound knowledge is indispensable to explain the development of Greek mathematics and astronomy. A knowledge of elementary geometry is not at all sufficient to interpret EUCLID.

is an inspiration. There are hundreds of good teachers for one original and complete scholar.

To be more specific, we might divide roughly all scientists into three groups : biologists and naturalists; physicists (including chemists and astronomers); and mathematicians. If the training of a prospective teacher had been chiefly biological, he might be expected to teach the history of science down to about 1800, with special emphasis on natural science and biological problems. He might give also a course on the history of biology down to our time, a course which would naturally culminate in a discussion of the main problems of our day and possibly in a vision of the future. In his general course, he should be allowed to skip over the mathematical subjects, though it should be made clear to him that he would improve his qualifications by a certain amount of mathematical study. In a similar way, the physicist would become a far better teacher of the history of science if he would study some biology. The best for him would be to spend his summer vacations in a biological station, like Naples, Wimereux, Roscoff or Woods Hole, where he could pleasantly divide his time between investigations along the beach and rocks, interviews with his expert colleagues, and microscopical or experimental work in the laboratory. The case of the mathematician may be more difficult. The pure mathematician — I mean the one with no experimental training and a marked predilection for the more abstract subjects — should not attempt to teach the history of science, though he might be able to give an interesting course on the history of logic and mathematics. The average mathematician, however, has received some training in experimental physics, and is interested in various applications. He might become an excellent teacher of the history of science, if he would spend his vacations in a biological station, undertake if possible some experimental research and take advantage of every opportunity to visit laboratories, workshops and mills. He should indulge in frequent discussions with engineers and inventors. They would gradually inculcate on him the difference between mathematical possibility (the absence of internal contradiction) and practical possibility. He should be made to realize it repeatedly in different ways and he should learn also to distinguish the many degrees of possibility and the conditions of each.

To sum up, the only unqualified scientist is the lopsided one, he whose knowledge is abnormally developed in a single direction and

who has lost touch with the rest of science (it is hardly necessary to point out his disability to him, for he is depressingly aware of it, but he will seldom admit the qualifications of others !). Of the specialized scientists, none is better prepared than the biochemist, if he has received a good mathematical and physical training. For his own speciality is located, so to say, at a strategic point; he has learned to appreciate the cardinal problems of many sciences. But even to him we should prefer the scientist who, after a long training both theoretical and experimental, has chosen for his life-work the study of general science — we might call him the specialized encyclopaedist. His particular training makes it much simpler for him than for any other scientist to observe the life and analyze the congruity of science, to watch its increasing unity amidst innumerable changes, to follow the growth of the tree of knowledge and of every one of its branches, to survey with comparative ease either the total knowledge of any one period or the evolution of some special science throughout the ages.

V

The historical method has been so often used in elementary and popular handbooks that to many people the phrase « history of science » conveys vaguely the meaning of « introduction to science ». The misunderstanding has been aggravated in America by the organization of courses on the history of science, which are professedly introductory. Their aim is to offer to the students at the beginning of the curriculum a sort of bird's-eye view of the whole of science in order to facilitate their choice of a proper direction.

There is little doubt that the historical method is excellent for that purpose. It is also the most natural one. Each man must somehow retrace the whole evolution of his ancestors. The historical method consists in replacing him in the psychological status of early man and in making him retrace step by step, though more rapidly, the intellectual progress of mankind. This method is extremely pleasant and suggestive, and it is remarkable how much knowledge can be imparted by its means to an intelligent audience. However, its limits are very quickly reached. The journey already accomplished by man is so immense that, even if one avails oneself of all the historical short cuts, the advance made possible by this method is too slow

and precarious. It is soon found necessary to use other methods which are almost the reverse of the chronological one. One starts from the latest notions instead of the most primitive, and one readily reconstructs the edifice of knowledge without reference to the accidents of discovery. In both cases the progress is from simplicity to complexity, but in the historical method the elements are simple by their concreteness, in the synthetic method they become simpler by increasing abstraction.

The use of the historical method is limited not simply by the lack of time, but also because as soon as one needs more than a bare outline, it becomes unmanageably complex. It is not possible to teach a subject and its history at one and the same time. The best method (one which every author has been gradually led to follow) is to give at first a brief historical outline which awakens the student's curiosity and makes it easier to define the field and the purpose of the science one is dealing with; then to abandon the historical order altogether and teach the subject in a systematical manner; finally to teach the history of the subject, thus enabling the student to review his knowledge from a different point of view and to deepen his understanding of it. The last stage — the true historical one — is frequently omitted, because its importance has not yet been fully realized and because the practical needs of the student are satisfied at the end of the second and he generally lacks the disinterested curiosity and the enthusiasm which are necessary to go any further.

Certain « introductory » courses written along the historical method (MACH's mechanics is the best example) are as simple as they are deep, but this simplicity is rather deceptive. At least the meaning of such books is disclosed only to those who have already a thorough knowledge of the subject. One encounters the same fallacy with regard to other elementary books. A summary is relatively richer in facts and meaning than a complete textbook, but the profit that we can derive from it is strictly dependent upon our memory of all the substance which it represents. The complete and seasoned scholar may find much to please and instruct him in a good elementary book, but it would be foolish to imagine that the same book will be equally instructive for an apprentice. Where the latter can but see a curious, if not a repellent, skeleton, the master will evoke at a glance the flesh and life around the dry bones. It takes a wise man to understand a primer.

When I am speaking of the history of science, I am not thinking of these historical introductions; it is hardly necessary to worry about them. The teaching I am thinking of is, on the contrary, a sort of conclusion to be offered only to advanced students, in their last year. It should be to them, before their departure from the college, the supreme humanistic initiation. It would involve a sort of synthetic review of their studies. They would have taken courses in science, in literature, in art, in history. This final course on the history of science would reveal to them the interrelations of all these parts, it would show them that they are but fragments of a single whole; it would expose to their view the magnificent harmony, the congruity, the unity of knowledge.

As I said a moment ago, an attempt has been made in some universities to offer such a course at the beginning of the curriculum, but it is then necessarily restricted to vague generalities and, even so, how much of it do the students understand? I think it is wiser to place it at the end, for a good deal of intellectual experience and maturity is needed to benefit by it: this teaching will be the more pregnant to each student that he has already acquired more knowledge.

Indeed, knowledge bears interest like money; the richer one is, the easier it is to get richer still; the more and better one knows, the easier it becomes to increase and improve one's knowledge. It is encouraging to realize, for example, that because of the unity and consistency of science, it is possible to understand its development much beyond one's own direct experience, that is, provided one's initial knowledge be sufficient and of good quality. If a student has taken the pains to carry on investigations along a certain line, and if he has conducted genuine experiments — experiments followed by frequent deceptions and perhaps finally rewarded by the discovery of a new fact, however humble — he will easily understand the meaning of other experiments not simply in the same field, but even in totally different ones. For the elements of experimentation are essentially the same in every field, and the most complicated and forbidding apparatus are made up of elements which are relatively simple and belong to a relatively small number of types. The same can be said of scientific method in general. An intelligent scientist can understand and appreciate the work of fellow scientists, even of those who are engaged in research widely different from his own. A

sound scientific initiation is indispensable to such understanding, but it does not matter sø much which. This comparison might even be pursued outside the sphere of experimental science. Let us again consider the history of religion, for example. It is clear that a scholar who has made a deep study of the development of one religion will find it relatively easy to understand the vicissitudes of another, for the human motives and the psychological problems involved are essentially the same in every clime.

As far as the scientific aspect of this teaching is concerned, it is hardly necessary to press the point : one's interest in the history of a thing can but increase as one becomes more familiar with it. The advantage of late instruction is not less obvious from the historical point of view, though a course on the history of science and civilization (that is, a history of civilization focussed upon the progress of science) can be made very interesting to an audience having but little knowledge of history. I have made the experiment more than once. I have lectured on Greek science and civilization, for instance, to boys whose whole past — whose living past — was at most two centuries deep : the depth of a skin. Yet I managed to entertain them and they entertained me too, for such ingenuity is not without charm. I prefer, however, to lecture to more sophisticated people, who have already obtained some sort of historical background and a sense of perspective. It is a great pleasure to be able to reveal to them that the history with which they are already familiar is not by any means the whole story, and to make them realize gradually that the history of mankind is double : political history which is to a large extent a history of the masses, and intellectual history which is largely the history of a few individuals (1).

The first development is the obvious one; it is the one which has thus far claimed the attention of historians almost exclusively. The peoples of the earth and, within each nation, the different classes of men, are not equally fertile, ingenious, energetical, ambitious. Their ambition — in the case of peoples one calls it, often, imperialism — is a function of their strength and vitality. If they become conscious of their superiority without being restrained by moral or religious motives, they are bound to become aggressive. Between strong, numerous, hungry people on the one hand and effeminated

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(1) For further development of the same idea, see my essay on Secret History, *Scribner's Magazine*, vol. 67, p. 187-192. New York, 1920.

people, weak, scarce and replete on the other, there arises, so to say, a difference of potential which, if it reaches a certain limit, causes a sudden disruption, — war or revolution. Political or economic history can thus be explained in terms of forces chiefly material. (At least in theory, for in most cases the complexity of causes is too great to admit of a strict analysis, and we must be content to register most historical disruptions as we register earthquakes or cyclones : we know the causes, but only in a general way, and our hold on them is very weak.) To be sure, other factors than the material must be considered — moral and religious factors, for instance, — but the fundamental causes are material. Leaders may exert a deep influence and modify the course of events, but only to a limited extent, for their energy remains always a function of the energy of their following. They can lead only to the extent that they avail themselves of existing passions, of the differences of potential which already obtain : they can not create these differences, but they can make use of them in various ways; they can delay the discharge or else provoke it and modify its nature.

The second development is far less obvious; in fact, so far as the majority of people is concerned, it is almost secret. Yet it is the development of the activities which are most specifically human, the development of all that is best in humanity : I mean the development of art, of science, of justice, of moral and religious ideals; in short, the creation and evolution of spiritual values. These values are created by individuals; in most cases, isolated individuals. CAESAR and NAPOLEON can not accomplish their destiny without the collaboration of millions; SPINOZA, NEWTON, PASTEUR do accomplish their own in seclusion. They thrive best in solitude. The elaboration of their sacred task — the very fulfilment of human destiny — is to a large degree independent of circumstances. At least, external circumstances seem purely accidental, not really creative. Society can poison SOCRATES, crucify JESUS or behead LAVOISIER; it can not cause them to be born, it can not dictate their task.

It is, as I said, a very great pleasure to reveal to a young audience this second but essential aspect of human history — the very course of human progress — for they know generally but little of it, and what they know has been obscured by the large mass of irrelevant and indifferent facts. They see kings enthroned, peoples in arms; they hear the clash of armies or of mobs; they may even hear the

impassioned orations of statesmen or rebels. But how could they see the poor philosopher working in his miserable garret; the artist wringing under the load of his inspiration; the scientist pursuing silently, obstinately his self-imposed quest? It requires more wisdom and imagination than they can possibly have to see these things. But they may know pretty well the historical background. It is then the estimable privilege of the historian of science to place in front of it the small but central figures.

Of course when the history of science is more generally known a greater place will be given to it in the regular courses of history, but even then the supreme historical teaching will have to be delayed until the end of the studies; it will remain a conclusion, not an introduction, for the reasons which I have already set forth.

As I see it now, historical teaching will proceed in the following way: the first teaching will be primarily political and economic; that is, the teacher will paint the background first. In later stages he will then introduce gradually the central figures and he will bring them out more distinctly as the knowledge and experience of the students increase: — the artist, the seer, the thinker, the scientist, the saint.

This order is the natural one. We must expect young students to be interested chiefly not in our highest but in our most primitive activities. Our deepest motives are centered upon such primal matters as food and shelter; love and hatred; business and play; health, disease and death. Besides, it is the abnormal conditions, not the normal ones, which excite the greatest curiosity. One needs the cold language of statistics to describe normality with any accurateness; but abnormalities are always sufficiently conspicuous; they need no barking at the door; they oblige us all to pause. It is not peace and plenty, therefore, but war and famine which interest the people most; not sanity, but insanity; not health, but diseases and plagues; not the soundness of love, but its perversions and irregularities. And the cruder the people, the more eager is their concern in monsters and oddities: the publishers of the yellow press know it full well. I will readily confess that when I am myself too tired to study or meditate, I have still enough energy to read the newspaper's gossip. That is, when my better self is exhausted, I can still draw upon the more primitive curiosity which is dormant a the bottom of my heart. All this explains why it is the conven-

tional history (one might call it the pathological history of humanity) which interests man first and most.

It is thus better perhaps not to quarrel with the old-fashioned historian : let him do as he is wont and give the people what pleases them most. They like to hear of wars and revolutions, of kings and princesses. They love the pageantry of the past, the pageantry and the scandals. Let them have them ! That is the background of the picture; they will have to know it at any rate, why not first ? There can be no objection to that, but we have a right to insist that some historical course, revealing the essential and putting matters in their true perspective, be given at the end of the curriculum. This would be the supreme humanistic initiation. And I add : let the historian of science do it, for he alone who is equally familiar with science and history, is fully qualified to explain the true nature of human progress.

VI

The history of science is an encyclopaedic discipline. It will stand or fall as we accept or not the possibility of encyclopaedic knowledge. I claim that such knowledge is both necessary and possible (1).

It is necessary as a coördinating and harmonizing agency; the very progress of special research would become more difficult without it. It remains possible because the increasing extension and complexity of science are largely compensated by its consistency and its progressive unification. To deny the possibility of encyclopaedic knowledge is almost as foolish as it would be to say that it is impossible to draw a geographic or geological map of the world. And yet such maps are being drawn, and they were already drawn a long time ago, when our geographical knowledge was considerably smaller than it is now. It is necessary to do it periodically, each time that science has reached a higher level, in order to inventory our knowledge, to determine more exactly our ignorance and to guide and ease further advance. To every stage of the progress of science there corresponds a stage of encyclopaedic knowledge which is, so to say, the image or the map of science at that particular time. The gaps of our knowledge are no obstacle to it : they are simply

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(1) I have developed this point in my paper on HERBERT SPENCER, *Isis*, III, p. 375-386. 1921.

the blank places, the *terrae incognitae* of the map, and nothing is more inspiring to the future explorer than to see them there and then in their proper relations to the better-known territories.

Encyclopaedic knowledge is not necessarily more difficult to obtain than any other. Nor is it necessarily vaster than any special ized knowledge, for its elements are different. There are as many names on the map of Massachusetts as there are on the map of the world, but they are names of a different kind. It is true, encyclopaedic knowledge requires special qualities; it is hopeless to attain it unless one be endowed with a synthetic intelligence. But that is equally true of any occupation : it takes a collector's mind to collect insects, at least to do it well; it takes a computer's mind to prepare a table of logarithms. It is easy enough if you have the right brains; it becomes impossible if you have not.

Encyclopaedic knowledge is relatively rare, not because of its difficulty, but rather because very few attempt to obtain it, or, if they do, do it in the right way. There is no tradition to help one, there are no traced roads to follow, and one can not become an encyclopaedist as passively as one becomes a physician or an electrical engineer. Yet the increasing specialization of knowledge will sooner or later make it imperative to create professional coördinators (1).

To quote a single example, it would not be unreasonable to expect university presidents to be encyclopaedists. It is true that under present circumstances (2), they have so much administrative work and so many social duties (outside of the faculty) that the training of a diplomat or of a banker may suit them better, and that they need entregent more than knowledge. However, as the administrative burden increases it will soon be necessary to divide the intellectual and the administrative functions, and the more so that they are essentially different. This may be the best way to check the progressive industrialization of American universities (3). There must

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(1) For the sake of concreteness, I propose to publish in an ulterior paper the outline of a complete curriculum. A course of seven years would be quite sufficient for anyone having already received a solid secondary education, such as is obtainable in a French *lycée*.

(2) It is the American conditions which I have particularly in mind in this paragraph.

(3) Of course this is partly caused by their tremendous growth. Every living creature has an optimal size. It is likely that there is also for each institution

be some coördinating agency between the members of the various faculties, and the coördination must be of the highest order; mere administrative coördination is almost worthless beyond its own limited range. The president to whom the intellectual leadership would be intrusted would need possibly an encyclopaedic education, and in any case a scientific one. Some fifty years ago it was assumed that a college president could be chosen only from among the theologians. Fifty years hence the presence at the head of a great institution of learning of a man having no other training than a literary or legal one, will appear as incongruous as that of a minister would now, and for the same reason. It will be generally assumed that the head of such an institution must have a minimal understanding of the activities over which he is expected to preside. Literary men, of course, will maintain that they do not lack that understanding, for few of them have yet realized the seriousness of their ignorance. But the plain, if unpleasant, fact is this : there can not be complete reciprocity between the literary man and the scientist, for the latter can understand the former, while the former can not understand the latter. Imagine an assembly of men who are supposed to deliberate and work together : one third can speak but English, another third can speak but Latin, and the rest are versed in both languages. Would it not be wiser (*ceteris paribus*) to select the leaders in the third group ? I give this comparison *faute de mieux*, but it is unsatisfactory, for it is far easier to translate from one language into another than to impart a scientific attitude to one who has no scientific experience. The encyclopaedic training would be the ideal one for a college president and for any man whose scientific duties are not specialized.

VII

The organization of courses on the history of science like those I am dreaming of — not introductory, but rather retrospective —

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an optimal size, beyond which it can not remain a *live* institution. But this abnormal growth is itself a symptom of industrialism. With the exception of a very few colleges (notably Princeton, Dartmouth, Bryn Mawr) the proportion of applicants who are refused admission is exceedingly small. It would benefit the Great Republic more to have fewer students and better universities. (Conclusions based upon figures published in the *New York Times* of Oct. 16, 1921).

would have far-reaching consequences. It would be the wedge by means of which encyclopaedic studies and the encyclopaedic point of view would gradually penetrate into our universities. It is partly because of this that I insist so much upon the history of science as against the histories of particular sciences. Such special histories are, to be sure, interesting enough, and their study should be encouraged to insure a deeper understanding of the science concerned; indeed, from the purely scientific point of view their interest is very great, but none of them can possibly have the same educational, humanistic bearing as the history of science. The progress of civilization is a function of the growth of knowledge in general, not of any special kind in particular. Besides, the evolution of each science is dependent in many ways upon the advance made by the others.

From this point of view, it should be remarked that the teaching of the history of science will not be simply one more teaching added to so many others, but will have a synthetic and coördinating value the importance of which can not be overestimated. Of course, this synthetic value will depend very much upon the personality of the teacher. But I am so convinced of its importance that I would fain say that the teaching of the history of science must be of a synthetic nature, or else that it does not deserve to exist.

But that is not all. The whole historical teaching will be gradually influenced by the history of science. Even if it be found expedient to leave to elementary teaching a purely political and pathological character (that is, if, as I now believe it, it is thought best to paint the background first), even then historians will be gradually impressed with the need of a scientific training. They will cease to be purely men of letters; driven between the archaeologists on the one side, and the historians of science on the other, their traditional ignorance of science will no longer be for them a matter of jest or boast, but a matter of shame. We have already attended a similar evolution with regard to geography. When I was a child, teachers of geography were literary men; their transformation into scientists has taken place so rapidly that before long a literary geographer will be as rare as the dodo. It is now generally understood that a sound knowledge of the structure of the earth, and of the soil, the meteorological conditions, the minerals, the plants and animals of each climate, is the natural introduction to geographical studies. That is, geology, meteorology and natural history are now considered as the

foundation of geography. Before the end of this century it will seem equally obvious that only those who are able to understand the elements of human progress are entitled to teach its history. The historical seminaries will then contain laboratories and small collections of natural history (as mementos!) and it will be recognized that for the average historian some knowledge of science is far more essential than a knowledge of heraldry or sigillography : the necessity of scientific propaedeutics will be generally accepted.

A good example of such preparation was given a long time ago by my dear master, EDWARD GIBBON. I quote from his autobiography this most interesting fragment (1) :

« After a short holiday, I indulged my curiosity in some studies of a very different nature, a course of Anatomy which was demonstrated by Dr. HUNTER, and some lessons of Chemistry which were delivered by Mr. HIGGINS : the principles of these sciences, and a taste for books of Natural History, contributed to multiply my ideas and images, and the Anatomist or Chemist may sometimes track me in their own snow. »

GIBBON did not pursue his scientific studies beyond this preliminary stage, yet he had clearly understood their importance, and scientists will have now one reason the more (if they did not know of it) for admiring him. If all historians took as much pains to approach the scientific point of view as GIBBON did, there would be less ground for complaining of their onesidedness, and the chasm between them and the scientists would not be quite as deep as it is.

The history of science will be the channel through which science will gradually penetrate into a system of education from which it has been thus far jealously excluded. It is through it that the humanizing value of science will first be felt. But well may the conservative hesitate to introduce it into the curriculum, for it will slowly but surely call forth a radical transformation of the whole system, a transmutation of educational values. The historians of science will constitute the vanguard of the New Humanism.

Cambridge, Massachusetts,
October 1921.

GEORGE SARTON.

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(1) The Autobiographies of EDWARD GIBBON edited by JOHN MURRAY. London, 2nd ed., p. 315, 1897. The fragment quoted refers to December 1777 ; GIBBON was then forty years old ; the first volume of the *Decline and Fall* had appeared the year before.

Michael Scot and Frederick II

In any judgment respecting the scientific activity of the court of Frederick II, much depends upon the opinion formed of Michael Scot, the emperor's astrologer, whose writings form a large part of the scientific and philosophic product of the *Magna Curia*. Condemned by Roger Bacon as « ignorant of the sciences and languages », Scot is praised by Gregory IX for his knowledge of Hebrew and Arabic, and addressed as *summe philosophe* by Leonardo Pisano, the most eminent mathematical genius of his time. Naturally enough for an astrologer, Scot early became a subject of legend, and the small body of fragmentary fact has not yet been winnowed from the mass of tradition. The elaborate biography by Dr. J. Wood Brown (1) contains far too much of pleasing conjecture, and its insecure chronology has misled more than one subsequent writer. It may help investigation if we try to set down the ascertainable events of Scot's life and to group his works in some chronological order, as a preliminary to an examination of his treatises on astrology and his intellectual relations with the emperor.

Concerning the place and date of Scot's birth no evidence has reached us. We may, however, be sure that when Master Michael calls himself Scot (2) he means a native of Scotland and not an Irishman, as the name frequently signifies in mediaeval usage. Not only did he hold benefices in Scotland (3), but he refused a most lucrative appointment, the archbishopric of Cashel, because he was ignorant of the Irish tongue (4). That he knew English appears

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(1) *An Enquiry into the Life and Legend of* Michael Scot (Edinburgh, 1897); followed closely in the article in the *Dictionary of National Biography*.

(2) « Cui ego Michel Scottus tanquam scottatus a multis et a diversis » : Bodleian. MS. Canon. Misc. 555, f. 45; infra p. 270. « Ego Michael Scotus » : Jourdain, *Recherches sur les traductions latines d'*Aristote (Paris, 1843), p. 127-129; MS. Pisa 11, on p. 252, below.

(3) Bliss, *Calendar of Papal Letters*, I, p. 102.

(4) *Ib.*, I, p. 98.

from a list of Anglo-Saxon names of months which he inserts in his *Liber introductorius* (1). The facts of his career place his birth somewhere in the late years of the twelfth century. Of his education we know nothing, the statements concerning his studies at Durham, Oxford, Bologna and Paris being mere guesses of modern writers. All that we can say is that his writings show a knowledge of the elements of Latin culture — the Bible, AUGUSTINE, the writers on the *trivium* and *quadrivium* — and that this was probably gained before he went to Spain for more special studies.

We must likewise dismiss as entirely baseless Dr. BROWN's chapter which makes SCOT tutor of the young FREDERICK II and author of various works composed in Sicily in 1209 and 1210. The sole foundation for this elaborate construction is the misreading as « MCCX » of the « MCC etc. » of a Vatican codex of the *Abbreviatio* AVICENNE (2); and there is no evidence connecting SCOT with Sicily until many years later.

The first specific date in SCOT's career is 18 August 1217, when he completed at Toledo his translation of AL-BITRODJI (ALPETRAGIUS) *On the Sphere* (3). He had plainly been for some time in Spain and

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(1) *Nomina mensium secundum Anglicos.* Primus mensis anni Anglorum est giuli, id est januarius; 2. est solmonant, id est februarius; 3, est heredemonath, id est martius; 4. est turimonath, id est aprilis; 5. est thrumiei, id est maius; 6. est lidan; 7. est lydi; 8. est vendmonath; 9 est aligmonanh; 10. est gyh. Hee gentes suum annum incipiunt a medianocte nativitatis Domini et quociens sunt kalende mensium tociens solempne pulsant campanas ecclesie maiori post complementum officii matutini cum interpollatione et omnes gentes summa devocione vadunt ad eandem ecclesiam portantes aliquid ad offerendum. Cod. Lat. Monacensis 10268, f. 71v.

(2) See the facsimile in BROWN, p. 55. Monsignore AUGUST PELZER of the Vatican Library informs me, as I had conjectured from the facsimile, that « MCC etc. » is the necessary reading of the original. I find that Sir JOHN SANDYS had also questioned BROWN's reading, but without rejecting the inferences from it (*History of Classical Scholarship*, third edition, I, p. 566).

(3) JOURDAIN, *Recherches*, p. 133, where one Ms. has the Christian and one the Spanish era. This is confirmed by MS. Madrid 10053 (ca. 1300, formerly in the chapter library at Toledo), f. 156v. : « Perfectus est liber AVENAL. AVENALPETRAUG a magistro MICHAELE SCOTTO Toleti in decimo octavo die veneris augusti hora tertia cum ABUTEO levite anno incarnationis Jesu Christi 1217 ». MS. BARBERINI Lat. 156 of the Vatican, f. 194, has 1221, but with the same day of the week and month. STEINSCHNEIDER, in Vienna *Sitzungsberichte*, CXLIX, p. 57 (1904), gives incorrectly 1267. Cf. MS. ARSENAL, 1035.